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AN ARCHITECTURAL APPLICATION FOR FCHART
(Solar Feasibility in the Midwest)

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Abstract

Examination of climatic conditions in the twelve Midwestern states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin reveals that this region receives from 50% to 70% of the possible annual total hours of sunshine.

Degree day heating requirements range from 4,000DD to over 10,000DD per year. In the northern tier of states, some areas require heat at some time in each month.

The FCHART Method for Solar Heating Design, developed at the Solar Energy Laboratory at the University of Wisconsin, is a method for making a computer study of solar capability for selected cities in the United States.

Thermal analysis of a selected typical housing unit was made by the FCHART method for thirty-two Midwestern cities. Percentage of heat provided by the sun varies from 87.8% in Dodge City, Kansas, to 70.5% in East Lansing, Michigan.

The sun provides the Midwest with sufficient rainfall and fine soils, so that this region produces 40% of the United States' agricultural output.

Despite this clear evidence of solar bounty to the region, the Midwest consumes 28% of the annual national energy budget, while contributing only 9% to this supply. (1)

Locally available renewable resources should be developed to redress this imbalance. Solar, wind and biomass (the latter two being solar-derived) are all suitable energy resources for the Midwest, which could help to balance the energy budget.

Examination of climatic conditions for the Midwest indicates an excellent condition for utilization of solar energy for space heating and cooling. Of the possible annual total hours of sunshine, this region receives from 50% in the northeast to 70% in the southwest.

We define the Midwest region as that served by MASEC, that is, the States of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.

In this region, degree day heating requirements vary from 4,000DD to over 10,000DD per year. (Figure 2) In the northern states, some areas require heat at some time in each month.

To determine the possible solar contribution for heating of residential space and domestic hot water, thermal analysis of a selected housing unit was made by the FCHART method for 32 Midwestern cities. (See Table A)

Parameters for the housing unit are consistent with solar heated residential projects designed by this office. Site-built collector design is also consistent with our typical office practice.

The FCHART program was developed at the Solar Energy Laboratory at the University of Wisconsin, as a method for most economical sizing of the collector system.

The program was modified for use at William Rainey Harper College by Joseph Yohanon and Robert Krawczyk.

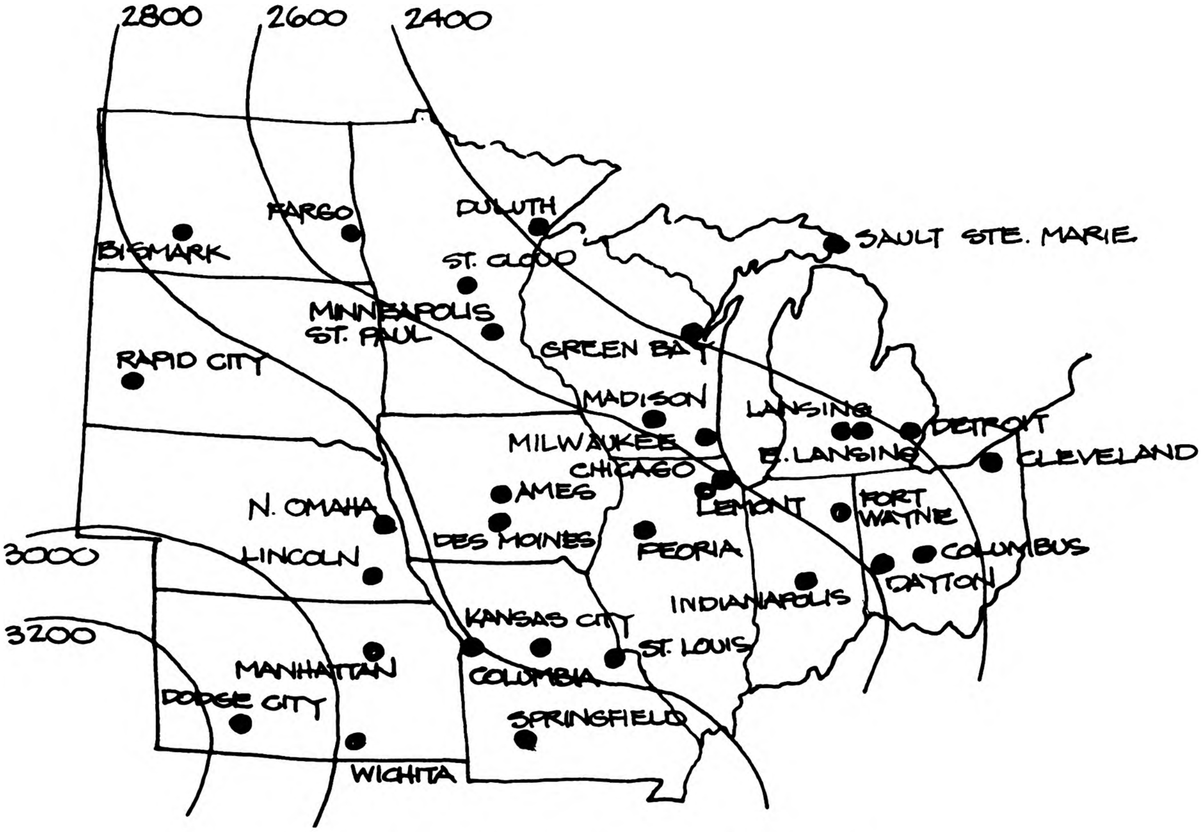

Figure 1 - Total Annual Hours of Sun for the Midwest

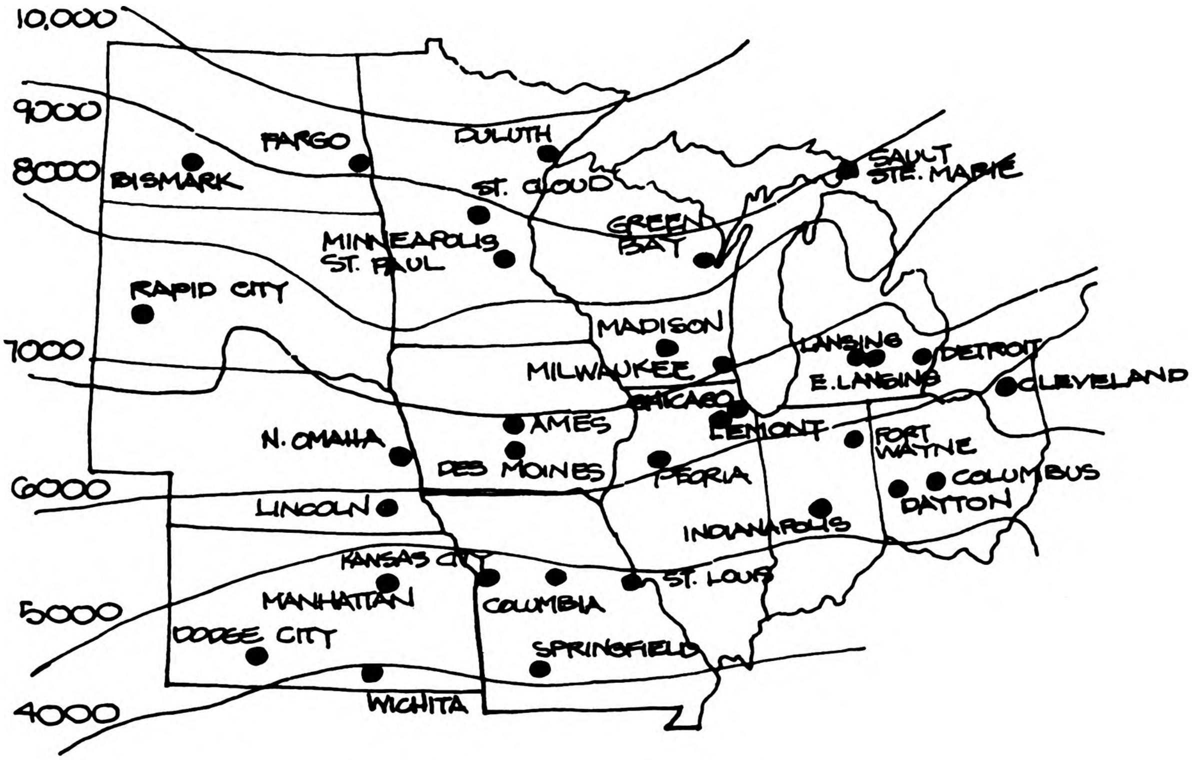

Figure 2 - Annual Degree Days for the Midwest

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LIST OF PARAMETERS USED IN THE ANALYSIS

CODE        VARIABLE DESCRIPTION                         VALUE UNITS

  1   AIR SYSTEM=1,LIQUID SYSTEM=2.................      1.00
  2   COLLECTOR AREA...............................    225.00 FT2
  3   FRPRIME-TAU-ALPHA PRODUCT(NORMAL INCIDENCE)..      0.50
  4   FRPRIME-UL PRODUCT...........................      0.50 BTU/H-F-F2
  5   NUMBER OF TRANSPARENT COVERS.................      2.00
  6   COLLECTOR SLOPE..............................     52.00 DEGRFFS
  7   AZIMUTH ANGLE (E.G. SOUTH=0, WEST=90)........      0.00 DEGRFES
  8   STORAGE CAPACITY.............................     15.00 BTU/F-FT2
  9   EFFECTIVE BUILDING UA........................     83.00 BTU/HR-F
 10   CONSTANT DAILY BLDG HEAT GENERATION..........      0.0  BTU/DAY
 11   (EPSILON)(CMIN)/(EFFECTIVE BUILDING UA)......      2.00
 12   HOT WATER USAGE..............................     79.20 GAL/DAY
 13   WATER SET TEMPERATURE........................    120.00 F
 14   WATER MAIN TEMPERATURE.......................     51.80 F
 15   CITY CALL NUMBER.............................     32.00
 16   THERMAL PRINT OUT BY MONTH=1, BY YEAR=2......      1.00
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Figure 3 - FCHART Input

Due to equipment limitations at Harper College, the program uses punch card input rather than interactive input. The FCHART is designed to select an economic size for the collector system by balancing collector output as a fraction of heat load required against costs of equipment and savings due to solar. For a thorough explanation of the method, see (2) SOLAR HEATING DESIGN and (3) HUD/MPS STANDARDS. Also note, as basic material (4) SOLAR ENERGY THERMAL PROCESSES. Figure 3 is an example of the input table printed out by the computer at Harper. The following is an explanation of the information required and of the examples used in this study.

Line 1: The collector system used is an integrated site-built flat plate air heater, with rock bin storage and heat exchanger for domestic hot water heating. The collector is detailed to use roof rafters as support and to avoid redundancy of materials over ordinary roof construction.

Line 2: A first approximation of collector size was made by using the Load Collector Ratio method developed by Balcomb and Hedstrom (5), estimated for 75% annual contribution. Collector areas used range from 150 SF in the southern Midwest to 250 SF in the north. The LC method uses a precalculated constant to predict collector performance based on building load. This estimation was made without reductions for heat gain. (See Line 9) The results in Table A show that the FCHART results agree to within approximately 10% with the LC prediction.

Lines 3 & 4: $F_R(\tau\alpha)_n$ and F_RU_L are the basic parameters of collector performance (4). F_R is the heat removal factor, or the ability of the system to remove heat from the absorber. $(\tau\alpha)_n$ is the transmittance-absorptance product at normal incidence. U_L is the overall collector heat loss factor. The values of these parameters for the collectors used have been determined in accordance with the MPS (3) and using data given by Kohler et al. (6). These parameters are unique to each collector configuration; however, in practice they show minor variations within a range of similar configuations.

Line 5: Two collector glazings are used for all locations.

Line 6: Collector slope is latitude plus 10^o.

Line 7: All collectors are assumed to face due south.

Line 8: Storage capacity of 15BTU/^{o}F-FT^2 is roughly equivalent to .5FT^3 of storage per FT^2 of collector surface. This amount of storage provides 3-4 average days of storage during the heating season.

Line 9: Effective Building UA is the heat loss in BTU/HR-^{o}F. In the interests of simplicity the thermal characteristics of the house used were not varied with location, though in practice a house built in southern Indiana would not be identical to one in Minnesota. The sample house is 1000FT^2 one story. Construction is frame walls and roof over unheated basement or crawl space. Walls are 2x6 studs with R-19 insulation and 4mil vapor barrier. The roof is insulated to R-38 plus vapor barrier. The floor is insulated to R-30. Windows are double-glazed. All entries are air locked. Further, the house is assumed to be designed to approach homeostatic with the climate, using placement and shading of windows, summer ventilation, landscaping, etc. Based on these assumptions the heat loss due to conduction and infiltration is 4800 BTU/^{o}F-Day which is equivalent to UA of 200BTU/HR-^{o}F. Because of the homeostatic design significant heat is gained through

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RESULTS FOR  CHICAGO          IL  LATITUDE  41.590

                **** THERMAL ANALYSIS ****

TIME  PERCENT  INCIDENT  HEATING  WATER  DEGREE  AMBIENT
       SOLAR     SOLAR     LOAD    LOAD   DAYS     TEMP
JAN    64.2       8.65     2.51    1.40   1262.    27.
FEB    71.6       8.42     2.10    1.26   1053.    28.
MAR    87.5      10.35     1.74    1.40    874.    37.
APR    95.1       9.41     0.90    1.35    453.    50.
MAY   100.0      10.60     0.41    1.40    208.    61.
JUN   100.0      10.59     0.05    1.35     26.    70.
JUL   100.0      10.78     0.0     1.40      0.    75.
AUG   100.0      11.39     0.02    1.40      8.    73.
SEP   100.0      10.81     0.11    1.35     57.    66.
OCT   100.0       9.90     0.63    1.40    316.    55.
NOV    64.6       6.79     1.47    1.35    738.    41.
DEC    50.5       6.66     2.25    1.40   1132.    30.

YR     80.2     114.34    12.20   16.47   6127.
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Figure 4 - FCHART Output for Chicago

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RESULTS FOR  INDIANAPOLIS    IN  LATITUDE  39.440

                **** THERMAL ANALYSIS ****

TIME  PERCENT  INCIDENT  HEATING  WATER  DEGREE  AMBIENT
       SOLAR     SOLAR     LOAD    LOAD   DAYS     TEMP
JAN    48.1       6.81     2.29    1.40   1150.    30.
FEB    66.0       7.79     1.91    1.26    960.    32.
MAR    89.9      10.72     1.56    1.40    784.    39.
APR   100.0      10.99     0.77    1.35    387.    52.
MAY   100.0      12.61     0.32    1.40    159.    63.
JUN   100.0      12.84     0.02    1.35     11.    72.
JUL   100.0      13.47     0.0     1.40      0.    75.
AUG   100.0      13.41     0.01    1.40      5.    73.
SEP   100.0      12.81     0.13    1.35     63.    66.
OCT   100.0      11.70     0.60    1.40    302.    55.
NOV    72.2       7.81     1.39    1.35    699.    41.
DEC    45.2       6.28     2.11    1.40   1057.    32.

YR     78.3     127.24    11.11   16.47   5577.
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Figure 5 - FCHART Output for Indianapolis

south facing windows. In addition, heat is generated by occupants, lights, cooking, etc. These factors reduce the actual heat demand. Based on actual projects and on a study done for AIA/RC we have assumed a reduction in the effective UA to 83BTU/HR-°F (1992BTU/DD).

Line 10: This line may also be used to take reductions in actual heat demand. For our purposes Line 9 is more concurrent.

Line 11: Does not apply to our systems.

Lines 12 & 13: Hot water usage is based on a family of four. The hot water supply temperature is assumed to be 120°F.

Line 14: While actual mains temperature will vary seasonally with location, a constant temperature had been used to simplify the study.

Line 15: The city call number is supplied by the program for 172 cities for which climatic data has been compiled. Of these, 32 Midwestern cities have been selected for this study.

Line 16: A monthly printout is desired to gain an idea of variation of performance over the year.

Additional input is required for an economic analysis of the system. We have not included these considerations for reasons stated below.

Figures 4 & 5 are examples of the thermal analysis as printed out by the computer at Harper. The first column is the percentage of monthly heat gain which is provided by solar. Second column is solar radiation incident on the collector in thousands of BTU/FT^2-Month. Third and fourth columns are the space and domestic hot water heating loads in millions of BTU/FT^2-Month. The fifth column is number of degree fahrenheit days for the month. Sixth column is the average ambient temperature for the month.

Printouts shown are for Chicago IL and Indianapolis IN. In Table A, the results of the study are set forth.

TABLE A

City	Latitude	Annual Degree Days	Collector Area	Annual Solar Contribution
Ames IA	42.02	6824	225	82.3
Bismark ND	46.47	9044	225	82.4
Chicago IL	41.59	6127	225	80.2
Cleveland OH	41.24	6154	250	74.0
Columbia MO	38.58	5046	175	80.3
Columbus OH	40.00	5660	225	75.5
Dayton OH	39.54	5641	225	80.9
Des Moines IA	41.32	6710	225	80.0
Detroit MI	42.14	6419	225	73.1
Dodge City KA	37.46	5046	150	87.8
Duluth MN	46.50	9756	250	75.3
E. Lansing MI	42.44	6904	225	70.5
Fargo ND	46.54	9271	225	72.3
Fort Wayne IN	41.00	6209	225	78.3
Green Bay WI	44.29	8098	250	75.5
Indianapolis IN	39.44	5577	250	78.3
Kansas City KA	39.17	5161	150	75.4
Lansing MI	42.47	6904	250	75.6
Lemont IL	41.40	6127	225	80.0
Lincoln NE	40.51	5867	175	80.6
Madison WI	43.08	7730	250	80.1
Manhattan KA	39.12	5182	150	76.4
Milwaukee WI	42.57	7444	250	78.3
Minn.-St. Paul MN	44.53	8159	250	76.3
N. Omaha NE	41.22	6612	200	85.4
Peoria IL	40.40	6098	225	79.8
Rapid City SD	44.09	7346	175	85.7
St. Cloud MN	45.34	8868	250	83.3
St. Louis MO	38.45	4750	175	79.0
Sault Ste. Marie MI	46.28	9048	250	76.7
Springfield MO	37.14	4570	175	85.8
Wichita KA	37.37	4687	175	87.4

The cities listed are the 32 Midwestern cities included in the program.

Location ranges from Springfield MO at 37.14 latitude to the northerly climate of Fargo ND at 46.47 latitude.

The annual degree days vary, with cities in the southern part of the region below 5,000DD, while cities in the north may have more than 9,000DD.

As previously discussed, collector area varies from city to city. Collector/floor area ratio is 15% to 25%.

This study clearly shows that, in selected Midwestern areas, at least a 70% annual solar contribution may be expected. The cities reporting the highest annual solar contribution are Dodge City and Wichita in Kansas, with 87.8% and 87.4% respectively. Here degree days are 5,046 and 4,687 respectively, among the lower heat requirements. However, such cities as St. Cloud MN with 8,868DD, Bismark ND with 9,044DD, and Rapid

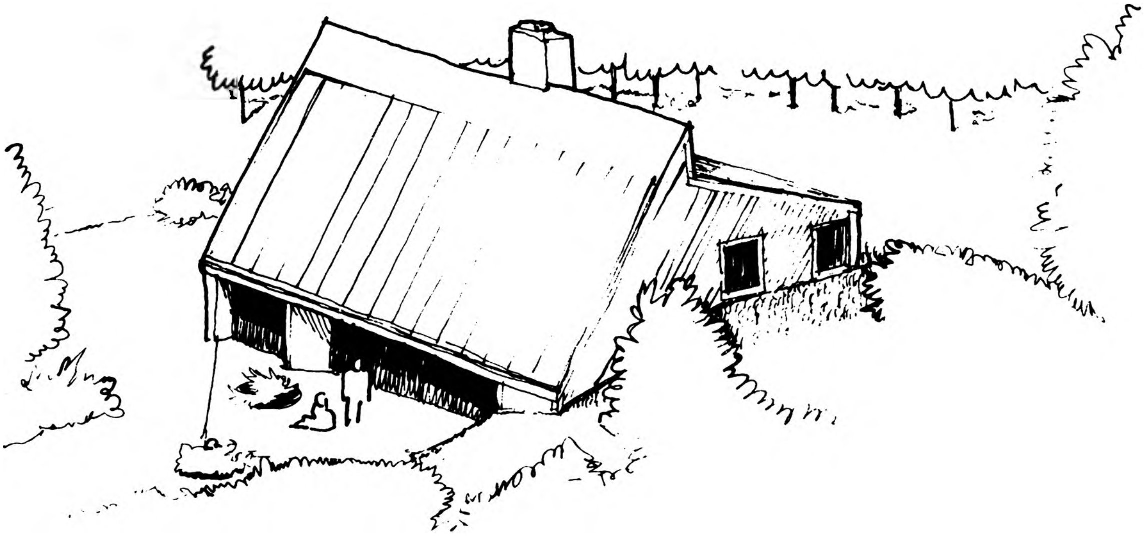


Figure 6 - Jablonski Residence, Waucanda IL

Figure 7 - Findling Residence, New Albany IN

City SD with 7,345DD have a potential annual solar contribution of over 80%.

Fifteen cities, nearly half of those studied, show more than 80% annual solar contribution. Mean percentage for cities studied is 79.1% space heating and heating of domestic hot water by the sun on an annual basis.

Only four cities report less than 75% annual solar contribution. It must be noted that, in at least one of these cities, microclimate strongly influences solar contribution. East Lansing MI with the lowest annual solar contribution, 70.5%, is in an area that is strongly influenced by Lake Michigan. Winds tend to travel from west to east across the lake. bringing a weather pattern of high precipitation and frequent cloud cover. Thus, although this city has less than 7,000DD, lower incidence of available solar radiation means a lower annual solar contribution.

Increased collector area is necessary in such areas to bring solar contribution to levels comparable to that in the remainder of the Midwest.

An additional possible contribution of up to 25% or even more can be achieved by carefully planned use of direct gain--that is, double glazed south-facing windows with insulating shutters. This additional solar use could raise the total solar contribution in all parts of the Midwest to close to 100%.

Printouts are shown for two cities--Indianapolis and Chicago. These cities were selected as examples so they could be illustrated by drawings of solar-heated residential units designed by this office which are located in the same climatic areas. (Figures 6 & 7)

These buildings were designed as homeostatic units, energy conservative, harmonious with the local climatic condition. (7)

Our buildings are ordinarily site-built and so are our flat plate collectors, which affords us greater design freedom. (Figure 8)

A site-built flat plate collector avoids duplication of materials. Collector and roof are integral, with collector materials replacing materials normally used in roof construction.

For a site-built collector, the south-facing roof of the house must be tilted at the correct angle for optimum solar gain, at latitude plus ten to fifteen degrees. Variance of the tilt angle within the ten to fifteen degree range is acceptable in order to provide the desired volume within the space. Roof rafters are placed in the normal manner. Twelve to eighteen inches of insulation is provided. Sheets of masonite are placed over the rafters or metal pans are placed between rafters to form the air channel. Over the air channel, there is an absorber plate of corrugated metal, painted flat black with a non-selective paint. Two layers of glazing (fiberglass or tempered glass) are placed over the absorber plate, spaced three-quarter inch apart.

How does this mesh with normal roof construction? The rafters are necessary. Insulation is normally used. Plywood sheathing is normally placed over the rafters. For the collector, metal pans or masonite sheets replace the sheathing. The absorber plate and two layers of glazing take the place of underlayment and shingles.

The trade-off between these materials and normal roofing materials greatly reduces collector cost.

It is difficult to pull out the costs of the collector system, built in this manner. Cost of the total heating system--collector, ductwork, controls, heat exchanger and pump for domestic hot water preheating, plus backup furnace--is between three and five dollars per square foot of the building.

Good workmanship is the key to success for these collectors. The same quality of workmanship that produces well-built structures will facilitate construction of a successful solar heating system. The workman on the job won't tell his boss that he cut the metal to the wrong size, leaving an air gap. Somebody--architect, contractor, owner or all of the above--will have to climb up to check the work.

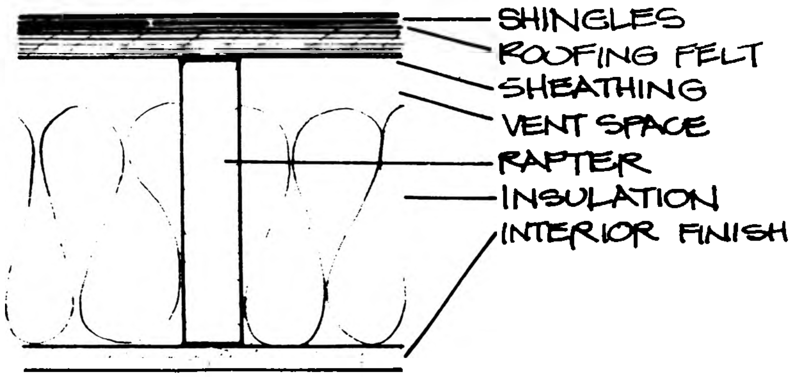
Examination of square foot building costs for solar-heated residences designed by our office throughout the Midwest indicate that these costs are in line with costs reported by other architects for conventionally heated, energy intensive residences.

We are experiencing square foot costs of $38 to $40, using integral site-built collectors. Comparable conventional residences in the Chicago area are reported at $35 to $55 per square foot. Six architectural firms with extensive residential experience were surveyed to provide this information.

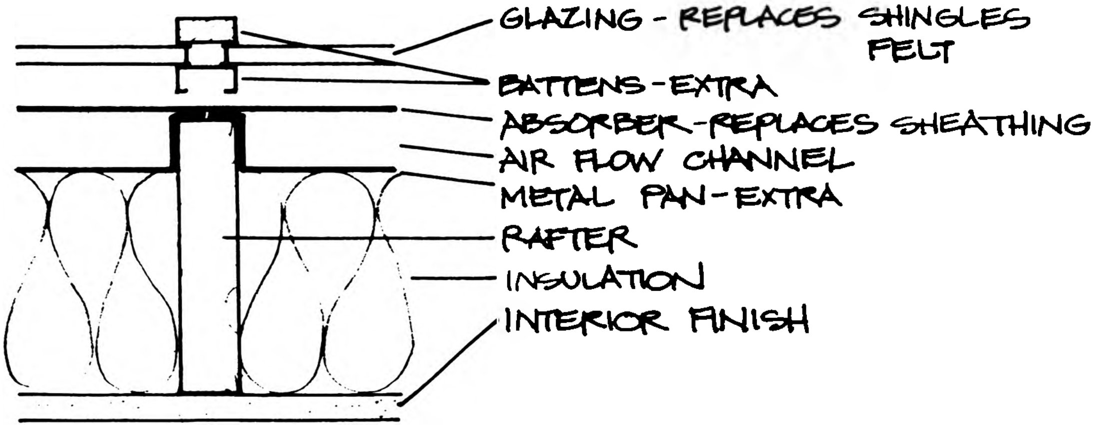
In view of cost similarities, we submit that economic analysis and discussion of payback periods is irrelevant, unnecessary and probably a confusing issue for the general public.

BIOGRAPHY

The Hawkweed Group, Ltd. concentrates on architectural and planning projects utilizing solar space heating, energy conservation and other alternate energy sources. Founded in 1960, by Rodney Wright, the Group chose, in



TYPICAL ROOF



SOLAR ROOF

Figure 8 - Comparison of Material Substitutions for Integrated Solar Collector

1974, to accept only commissions that had an alternate energy component. More than fifty projects are at some stage of development, from completion to drawings. Partners are Rodney Wright, Architect; Larry Dieckmann Architect; Robert Selby, Architect; Sydney Wright, Planner.

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